PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

World Setting: Large Estates and Capital-Intensive Enterprises [and Discussion]

G. R. Hoffman, R. F. Stoner, T. W. Tanton and Mary Tiffen

Phil. Trans. R. Soc. Lond. A 1986 **316**, 217-228
doi: 10.1098/rsta.1986.0005

Phil. Trans. R. Soc. Lond. A **316**, 217–228 (1986)
Printed in Great Britain

World setting: large estates and capital-intensive enterprises

By G. R. Hoffman & R. F. Stoner
Sir Murdoch MacDonald and Partners, Demeter House, Station Road, Cambridge CB1 2RS, U.K.

Capital-intensive irrigation schemes occupy only a small percentage of the irrigated land in the world, but their contribution to total production is out of all proportion to their size. Examination of the development of irrigated agriculture in the recent past can help in recognizing the most promising trends, so that world agricultural production can be given a chance of keeping pace with the increasing demands. Capital-intensive schemes may point a way ahead, by identifying research needs and providing a proving ground for new technology as it becomes available. The worldwide transfer of this technology is the main hope for the future.

Scientists and engineers have a vital part to play in developing and applying the new technology that is so urgently needed.

Introduction

The total area of arable land in the world is, at present, *ca.* 1500 Mha. Of this, about 16% or 250 Mha is irrigated and, in this irrigated area, only about 50 Mha is farmed with the use of technology that is more advanced than the shovel. Only a proportion, located almost exclusively in the countries of the developed world, of those 50 Mha can be said to be farmed by using modern technology.

This paper is concerned with this more sophisticated type of irrigation. The area of such schemes may be small in the world context but their output in terms of agricultural production is out of all proportion to their size. Scientific irrigation makes it possible to obtain average farm yields many times greater than those obtained by 'traditional' farming methods. We are told that the San Joaquin Valley in California produces 25% of the food of the U.S.A. from 2% of its farmland: the agricultural statistics for mainland China (Framji 1984) show that the value of agricultural production from the 46% of land which is irrigated was 66% of total agricultural production in 1980; on a world basis it has been estimated (Framji *et al.* 1981) that the 16% irrigated area produces crops valued at 34% of world total production. These last two results reflect the average productivity of irrigated land; the relative proportion contributed from high technology irrigation must be very much higher.

Whatever the true overall figure, two questions need to be asked. First, can some of the advanced technology now used in a very small proportion of irrigated lands be expected to extend to irrigation schemes worldwide with the consequent enormous increase in food production? Secondly, if so, how long will it take? The answers to both questions depend upon factors such as the suitability of soils and climates and whether returns on investment are high enough, and farmers are capable and motivated, etc. But it must be accepted that the 'developed' countries were once 'developing', and so it may be assumed that, at any one moment in time, any country or region is seen at a particular point in its continuous march towards 'development'.

Such progress is achieved through the application of research to pilot schemes and the subsequent transfer of the new technology throughout the industry. In this century, technology has been advancing at an increasingly rapid rate, and as a result the developing world has the opportunity to move forward faster than ever before: the necessary technology is already available. It does seem that irrigating countries generally are profiting from this, and provide examples of the successful transfer of technology that is essential for continuous progress. It is possible, therefore, that an examination of past performance may give some guidance on whether high-technology farming can expand appreciably in the developing world and at a significant rate.

The general picture

Published statistics worldwide show some striking trends in the agricultural sector. Over the last 20–25 years almost all of the 125 countries listed in the *World development report* (World Bank 1984) show a fall in the proportion of their labour force engaged in agriculture and a corresponding increase in employment in industry and services (see table 1).

Table 1. World labour force allocation between agriculture, industry and service: 1960 compared with 1980

type of economy	number of countries	allocation of labour (percentage): agriculture 1960	agriculture 1980	industry 1960	industry 1980	services 1960	services 1980
low income	34	77	72	9	13	14	15
lower–middle income	38	71	56	11	16	18	28
upper–middle income	22	49	30	20	28	31	42
high income oil exporters	4	62	46	13	19	25	35
industrial market	19	18	6	38	38	44	56
E European (non-market)	8	42	18	30	44	28	39

The figures in table 1 also indicate a connection between the income of a country and the percentage of its labour force that is engaged in agriculture (apart from the four high-income oil-exporting countries). If low-, middle- and high-income countries in the World Bank's definition can be taken to indicate a progression from the 'developing' to the 'developed' state, then the state of development of a country, d, appears to be inversely proportional to the percentage of labour force engaged in agriculture, l: that is to say $d \propto l^{-1}$.

If the proportion of the labour force in agriculture is getting less, what is happening to productivity per worker? Such a measure of productivity might be expected to be higher in the more developed countries. In other words, the state of development (d) may be directly proportional to the productivity per agricultural worker, p: that is to say $d \propto p$.

If the percentage of the labour force in agriculture is plotted against the productivity per worker for different countries it should therefore produce a curve of a general hyperbolic shape. This is of course, the result: figure 1 gives the curve for 1980 plotted from statistics published by the World Bank (1983) and figure 2 compares this curve for 1980 with similar curves for 1960 and 1970.

In such a broad approach the many inconsistencies of climate, soils, population density and

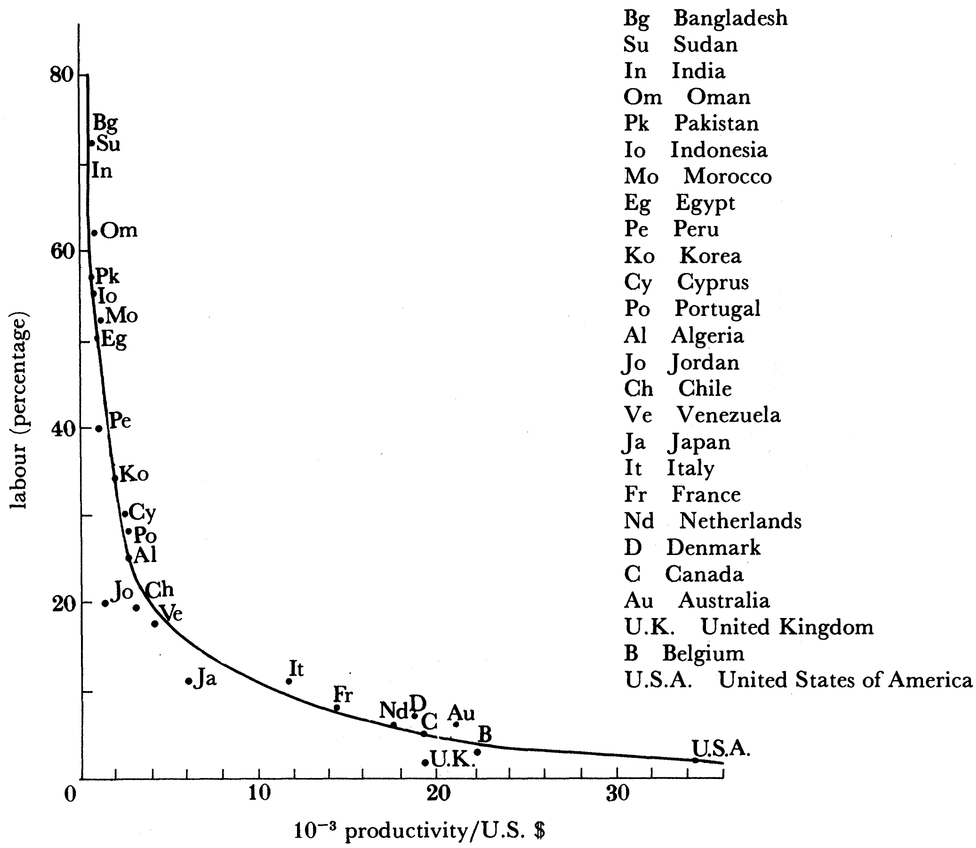

FIGURE 1. Percentage of labour force employed in agriculture plotted against productivity of agricultural workers (agricultural G.D.P. *per capita*) for developing and developed countries in 1980.

so on between different countries are necessarily ignored. In spite of this the plotted points for 1980 lie close to the smooth curve of figure 1 and the same is true for the two other years, 1960 and 1970. In fact the three curves of figures 1 and 2 have been fitted to the points by using a least-square error technique and the multiple correlation coefficients for all three lie between 0.95 and 0.96. The equations of the curves are of the form:

$$y = a + b/x^{0.4}.$$

The fact that 1960 and 1970 show almost exactly similar characteristics to the 1980 curve indicates that a definite relation exists. However, because of the complexity of establishing relevant inflation factors for each of the countries plotted, no attempt has been made to reduce all the figures to 1980 prices.

The curves show that the transition from developing to developed country involves the often painful transfer of workers out of agriculture and into industry and services. Indeed, F.A.O. estimates for the future (F.A.O. 1983) show the proportion of the agricultural labour force of developing countries reducing from an average of 60% in 1980 to 43% of the total labour force in 2000. But because ever-growing populations require continuously increasing food supplies, the reduction can only make sense if productivity *per capita* is actually increased as the proportion of the labour force gets smaller. The fact that this is happening is confirmed by the curves in figures 1 and 2.

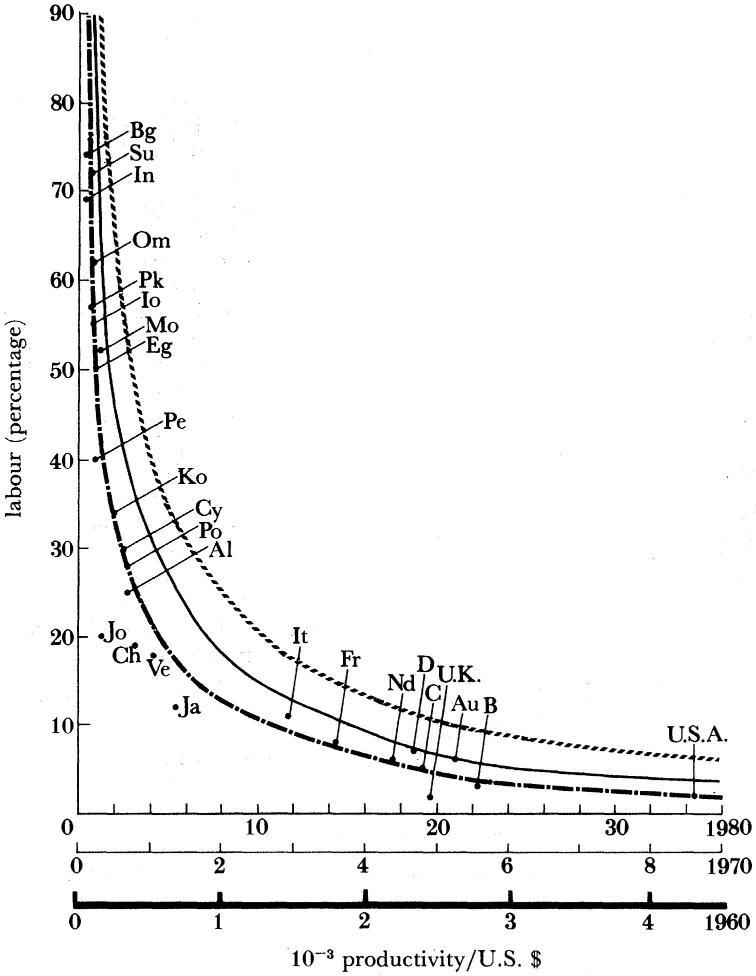

FIGURE 2. As figure 1. Broken line shows data for 1960, full line shows data for 1970, compared with 1980 (chained line). Country code as in figure 1.

Is this, perhaps, some fundamental irreversible social change resulting from the continuous advance of science? Indeed, it may be that increased labour productivity on the farm is the essential starting point for progress towards 'developed' status. Not only can it enable agricultural output to keep pace with the ever-rising needs of growing populations, but it ultimately helps to bring about a reduction in the proportion of labour engaged in agriculture and an increased potential for industrial activity.

The course of events in the 'development' of a country might be as follows.

(i) Increasing the numbers of farm workers as population increases.

(ii) The area of cultivation is increased up to the limits of available land or water (or both).

(iii) Farm sizes are reduced: productivity per hectare is increased but productivity per worker gets less.

(iv) Workers start seeking off-farm employment – either light industries, cottage industries, etc., or through migration to the cities.

(v) Labour shortages on farms arise at peak periods.

(vi) Mechanization is introduced, leading to increased productivity per worker.

(vii) Subsistence farming is replaced by commercially oriented agriculture and increasing profitability.

(viii) The demand for consumer goods grows, leading to growth in the manufacturing industries and increasing opportunities for labour in industry.

This progression can create a transitional period when surplus labour from agriculture cannot find employment in industry. In other words, stage (iv) may well be the critical point for many countries. In the short term, therefore, what may be needed in a number of developing countries is advanced agricultural technology involving labour-intensive techniques. This does not mean abandoning mechanization altogether, because selective mechanization to cater for short-term peak labour requirements can result in an increase in total base-labour inputs.

The growing pressure of population on the land is already causing the average size of holding to fall in several of the developing countries. If the progression listed above is correct, this is only one of the predictable steps on the road to developed status; but it is sometimes used in reactionary arguments by those who consider that the new technology wrongly favours large farms at the expense of the small.

This whole process of change assumes considerable importance when viewed in the light of the observation that the smaller the percentage of labour force engaged in agriculture the lower the crude birth rate. This was noted by Robert McNamara in an address to the Massachusetts Institute of Technology (McNamara 1977). He went on to say that the desire for smaller families must precede the implementation of the means to effect this and that increased productivity in agriculture assists in creating this desire. If all this is true, increased productivity or the application of higher technology in agriculture must be of fundamental importance to future generations and may be a major factor in the control of population increase.

Rate of change

How long, then, could it take for the transfer of modern technology to affect agricultural productivity in the developing countries? An Asian Development Bank paper (Kunio Takase *et al.* 1968) gives data for yields of paddy rice in Japan going back nearly 1400 years. These data are plotted in figure 3.

The authors of the paper divided the remarkable ninefold yield increase into four stages.

Stage 1. Primitive farming where the water was supplied by rainfall or natural flooding – yields less than 1 t ha^{-1}.

Stage 2. Water control: this involved irrigation, drainage and flood control – yields gradually rose to some 2.5 t ha^{-1}.

Stage 3. Technical innovation: the introduction of fertilizers, pesticides and improved varieties of rice. As a result average yields climbed rapidly to 3.5 t ha^{-1}.

Stage 4. Structural reform: improved cultivation methods, mechanization, crop diversification, adjusted sowing and harvesting dates for optimum rotations. These inputs caused the greatest increase in average yield taking it up to 6 t ha^{-1} by 1965. Present yields in Japan are in the region of 6.75 t ha^{-1}.

This picture of the progressive introduction of high technology into rice-growing in Japan illustrates an important point – in the tropical rice-producing areas of the world, the introduction of water control (stage 2) is not just one of a number of inputs for improving

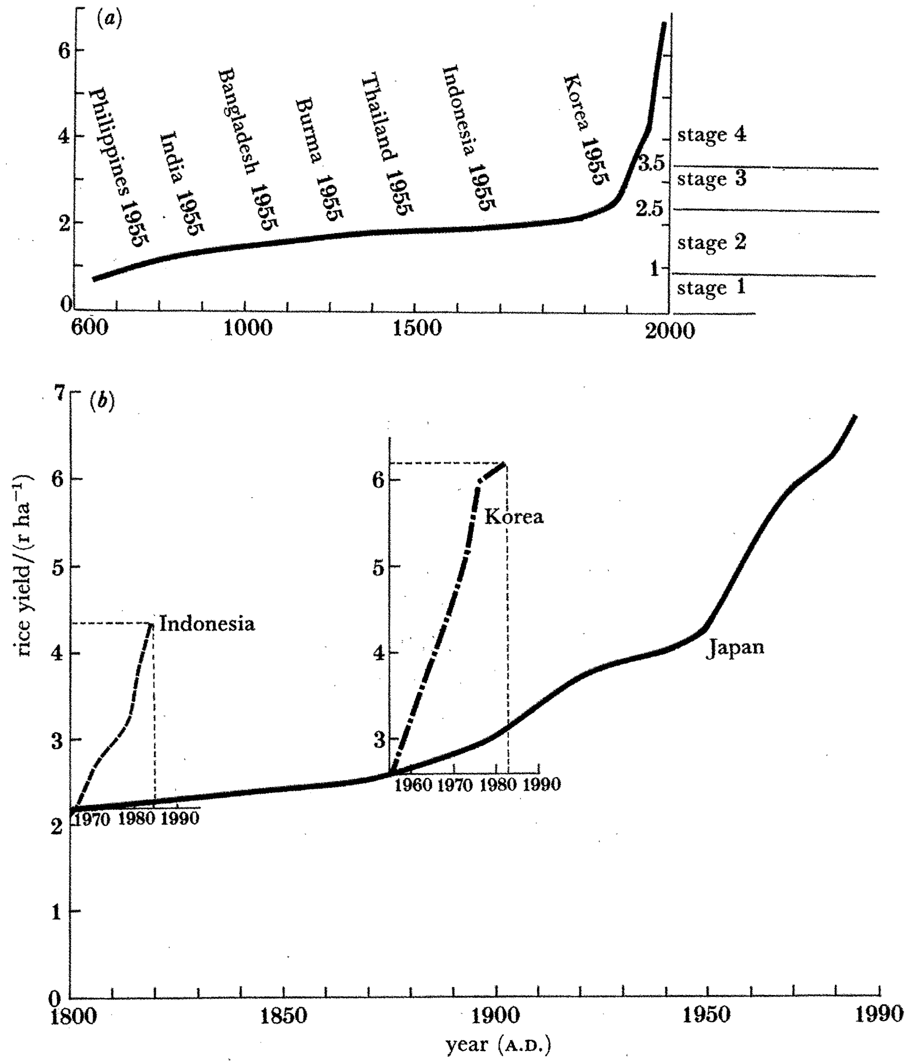

FIGURE 3. (*a*) Growth of paddy rice yields in Japan. (*b*) Growth of yields of rice in Indonesia and Korea compared with Japan.

production: it is an essential infrastructural operation which has to be effected in advance, before stages 3 and 4. Otherwise, as has been found, the other inputs, such as high-yielding varieties, fertilizers, pesticides, improved cultivation methods and so on, will produce only nominal disappointing increases in average yields which may not justify the expense involved.

Figure 3*a* shows that Japan took some 1100 years in introducing water control (stage 2), during which time the rice paddy yield rose from 1 to 2 t ha^{-1}. Stage 3 (technical innovation) took 100 years and stage 4 (structural reform) started at the beginning of this century.

Other countries of the Far East were almost all at various points in stage 2 after the war. The average paddy rice yields in 1955 for a number of the major rice-producing countries of Asia are marked on the curve of figure 3*a*. Since the war large sums of money have been spent on water control and technical innovation in these countries, with varying degrees of success. Because much of the new technology was available to them, they have been able to advance much faster than Japan, which was breaking new ground all the way.

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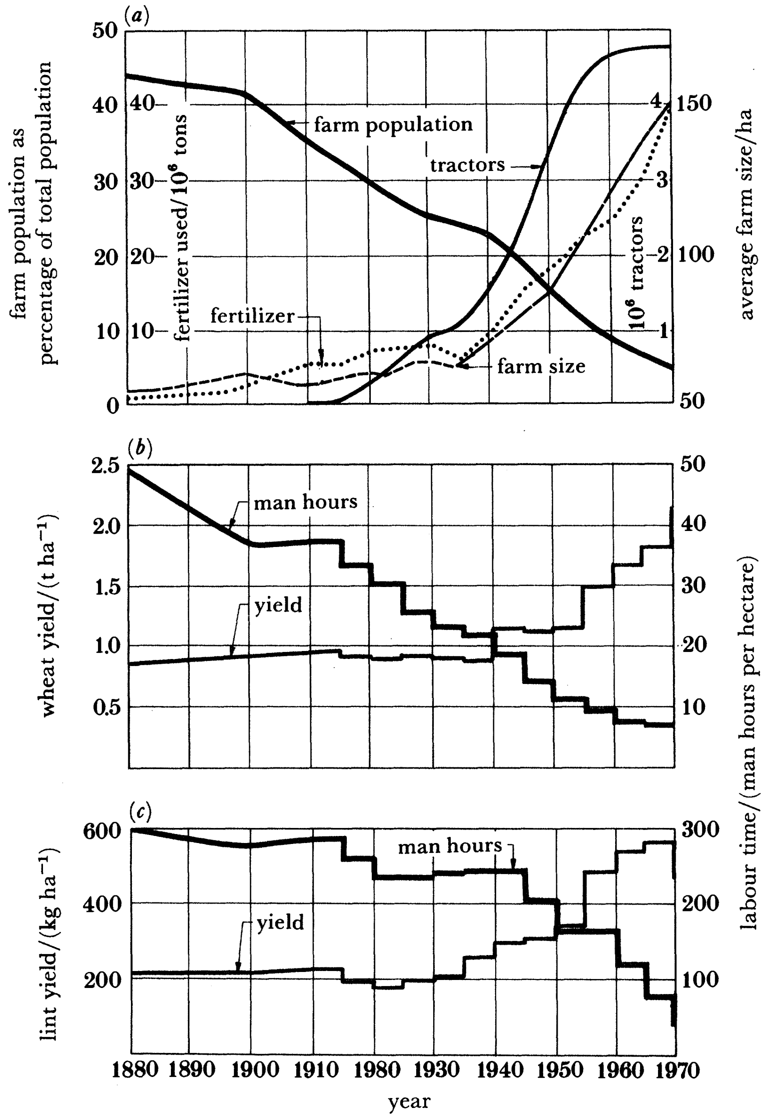

FIGURE 4. Agricultural development in U.S.A. (*a*) Farm population dynamics, fertilizer use and mechanization; (*b*) effect of changes in (*a*) on wheat production; (*c*) effect of changes in (*a*) on cotton production.

Two of the most successful have been Korea and Indonesia, and figure 3*b* compares their rates of progress in raising yields with that of Japan. In the space of 27 years from 1955, Korea has been able to increase paddy yields from 2.6 to 6.2 t ha^{-1} (Herdt 1983), which practically equals the Japanese figure. Similarly, a concentrated, sustained effort on a very large scale by Indonesia resulted in the average yield of wetland rice increasing from 2.1 to 4.3 t ha^{-1} in 19 years from 1965. (Figures produced by the Indonesian Statistical Office.)

Another example of progress towards development in agriculture is obtained from the United States, where statistics are available for the last 100 years (U.S. Department of Commerce 1975).

Figure 4*a* shows how the proportion of the population living on farms fell steadily from just over 43% in 1880 to $4\frac{1}{2}$% in 1970, while the average farm size increased from *c.a.* 60 ha to over 150 ha. This consolidation of holdings accelerated towards the end of the period as farming became more and more commercially oriented and as mechanization began to influence productivity. Figure 4*a* also shows the rapid and accelerating growth in the use of fertilizers, closely followed by the increasing use of tractors (and other forms of mechanization not shown here): these correspond to the major elements in Takase's stages 3 and 4 in the progress towards maximizing rice yields.

In figure 4*b*, *c*, the effect of the above changes on the yield and labour requirement are shown for two major crops – wheat and cotton. The yield increases are very significant in the final 30 years of the record, but the reduction in labour requirement to about one sixth of that at the beginning of the period is remarkable and reflects the economic advantage of mechanization in an economy where labour costs are high.

Let us now go into more detail, and look at a specific enterprise at the upper end of the technology scale. Green's of Soham, an East Anglian group, has been developed by two brothers from some 2000 acres† in the early 1960s to an area of 7000 acres of highly productive land today. The growth in area took place over the first sixteen years: the last four or five years has seen a continuous improvement in technology and a concentrated effort to establish markets both in the U.K. and Europe.

The main crops grown are vegetables (potatoes, celery, onions, leeks, etc.) with one-third of the area used for a cereal breakcrop (wheat). Irrigation is used for the major crops and covers *ca.* 40 % of the total area: the aim is not so much to maximize yields as to obtain constant yields of high quality, although potato yields have risen over the years from 11–15 tonnes per acre to the present level of 18–20 tonnes per acre.

Irrigation is generally by rain-gun sprinklers, but they have now installed a comprehensive sub-irrigation system in one area where the soils and topography are particularly suitable, and are introducing linear-move irrigators elsewhere because this gives more accurate control of water applications to suit the different stages of crop growth. Computer models are used to predict the general level of water requirement for overall planning, the final decision being made at field level from inspection of the soil and crop.

All these developments demand high technical competence at management level to justify the expense involved. Sub-irrigation, if not properly controlled to encourage optimum root development, can cause lower yields or even complete crop failure. Overhead irrigation is an expensive investment and, unless correctly applied to provide the varying crop water requirement at different stages of growth, frequently leads to overwatering and the consequent losses through unnecessary pumping costs and the leaching out of expensive fertilizer. Fertilizer applications are now more scientifically based, resulting in lower use rates with no reduction in yields.

High technology is thus vital to the survival of this enterprise and the group keep in close touch with the latest developments in research. They are co-operating with Rothamsted Experimental Station, which is conducting trials on their land, and they support research generally, for example through the setting up of the Cambridge University Potato Growers Research Association.

The structure of the organization is based on five partnerships, each with a managing partner responsible to a board of directors, and each employing about 14 tractor drivers (one to each 100 acres) one fitter and a storeman. The farm managers are college or university trained, and the other employees have the appropriate technician training. Packaging and marketing are

† 1 acre ≈ 0.405 ha^2.

centrally organized and employ the largest number of staff; a small administrative and advisory group is also located in the Soham office (see table 2).

Table 2. Employment of workers in Soham group

farm managers and assistants	8
tractor drivers	70
fitters	5
storemen	5
packaging, administration, advisory	350
total	438

The number employed works out at an average of one worker per 16 acres ($6\frac{1}{2}$ ha). The U.K. average in 1980 was about one agricultural worker to over 60 acres.

This example is clearly not capable of extrapolation throughout the developing world, although there is certainly a place for such enterprises on a limited scale. It does, however illustrate some of the fundamental differences between capital-intensive, commercially orientated schemes in the private sector and the traditional subsistence agriculture which exists throughout the developing world. Paramount among these are the need for trained personnel, the dynamic attitude to innovation and research and the integration of packaging, marketing, etc. into the operation. This last point is worth stressing because it does indicate that high-technology farming, while reducing the number employed on the land, has created new jobs in packaging and marketing. The simple fact of increasing production on the farm must result in additional labour requirements for storing, transporting and marketing the produce.

On the other point, training, technology transfer or whatever it may be called, it is worth quoting Schultz (1964):

> '...the man who is bound by traditional agriculture cannot produce much food, no matter how rich the land.... To produce an abundance of farm products requires that the farmer has access to and has the skill and knowledge to use what science knows about soils, plants, animals and machines.'

The future

Referring back to the two questions posed in the opening paragraphs, it would appear that capital-intensive, modern technology is being gradually adopted in the more progressive countries of the world, but it may take 20–40 years for the full effects to be realized in any one country. The problem in extending this on a global basis is that all countries are in different stages of the development process.

At one end of the scale, the so-called developing countries are generally characterized by subsistence agriculture with low productivity per worker and small farms. At the other end, the developed countries have highly productive agricultural sectors in which productivity per worker is high, and land has been consolidated into large holdings. The transition from one to the other involves fundamental social changes and immense problems in absorbing labour that is surplus to agricultural requirements into alternative, wealth-creating, employment.

The solution to these problems must be specific to a given country's stage of development and resources, but measures to raise productivity are of vital importance, whatever other policies may be appropriate.

The question currently occupying the minds of the planners is whether efforts should be concentrated upon raising productivity per hectare rather than productivity per agricultural worker; i.e. labour-intensive or capital-intensive development? While it is agreed that priority must be given to the former in certain countries, it should be recognized that subsistence agriculture may well persist if farms get progressively smaller, labour-intensive low technology is adopted, and output per worker stagnates – even if productivity per hectare is substantially increased. Really productive farming, using high-technology methods seems to require large, not small, holdings.

The question must therefore be asked – is it inevitable that progress towards developed status requires higher productivity per worker, implying the need for high technology and larger farm holdings?

If the answer is in the affirmative, then present 'conventional wisdom', which concentrates on the small farm, is dealing with an interim state, applicable to some but not all of the developing countries, depending on their particular situation. Such a policy can do a great deal of harm if applied in the wrong places, as Mr Robertson (this symposium) has already pointed out.

Does the future, therefore, lie with the large estates and capital-intensive enterprises? There are three reasons why they should be given a priority in present planning. First, they have the greatest potential for rapidly increasing production; but it must be appreciated that in the developing world they depend absolutely on the effective transfer of technology, efficient operation and maintenance, and the capacity and ability to absorb displaced labour into non-agricultural productive work. Secondly, capital-intensive projects which are properly operated and managed can act as demonstration or pilot schemes to assist the promotion of the new technology in a region or country. They thus provide a comparatively rapid means of spreading modern technology and reducing the gap between potential and actual yields at farm level.

Lastly, large high-technology enterprises play an important part in generating research by identifying problems, trying out new techniques, and cooperating generally to advance the state of technology with the object of achieving ever more productive and efficient farming.

The world has embarked on a technological revolution that is as fundamental as the industrial revolution of the eighteenth century. The sooner this fact and the implications for all of us are understood the better our future will be. The industrial revolution caused a major upheaval, and changed most of Western society from the stagnant agricultural civilization which had been reached in the seventeenth and eighteenth centuries to the dynamic industrial society of the nineteenth century. It is evident that those countries which grasp soonest the opportunities for advancement will be the earliest to achieve an acceptable standard in the new society.

I believe that we must actively encourage the managers and operators of advanced, capital-intensive irrigation enterprises to demand ever better equipment, seeds, pesticides, and knowledge of farming methods so that they can apply these to the production of ever greater yields at more and more economic prices.

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Discussion

T. W. Tanton (*Institute of Irrigation Studies, University of Southampton*). I would like to question the interpretation of the graph that was used to show that 'depopulation of the land improved productivity'. To me, the data indicate that for most countries, there was little relation between productivity from the land and the number of workers on it. However, a few industrialized countries have been able to subsidize farmers, from profits from industry, to develop high-technology agricultural systems. It is clear that such modernization and depopulation of the land is a result of an active industrial sector. The importance of this subsidy is brought home by the fact that the average British farmer uses three times more fossil-fuel energy to support crop production than the consumable energy that he actually produces, while the poorest peasant farmer requires almost no fossil fuels for crop production. I therefore consider that high-technological intensive farming, as we know it today, is only applicable in very highly subsidized farming systems.

G. R. Hoffman. The graphs of figures 1 and 2 to which Dr Tanton refers show that the productivity of agricultural workers appears to bear a relation to the percentage of the labour force engaged in agriculture. It must be appreciated that for a given country the number of agricultural workers per unit of cultivated area changes with time as both the population and cultivated area increase. The curves of figure 2, however, show that the relation between the percentage of labour force engaged in agriculture and the productivity of agricultural workers has retained the same form over the 20 years from 1960 to 1980, and examination of individual countries does indicate that they have moved down the curve over that period. Of course those countries with a high population density, high birth rate and limited land resources may be at a point of saturation of workers in agriculture and are thus trapped in a subsistence situation, although year by year the percentage of labour engaged in agriculture will fall as the surplus population drifts to the cities. However, this is at the upper end of the curve and does not necessarily invalidate the general statement.

As stated at the beginning of the paper, there are many factors that determine a country's state of development: physical, economic, social, and political, and the curves shown in the paper are a gross *pot pourri* of all these factors. We would say to Dr Tanton that within this mish-mash one element involves implicit and explicit subsidies and taxes and it is not true that

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only the lower arm is affected. At the poorer end of the curve there are hidden subsidies in that water charges are often, and capital charges almost never, recovered. To some extent the matter is redressed by pricing policies that fail to pay the farmer adequately for his produce and thus are effectively hidden taxes. In effect this recognizes the political and social need to subsidize the urban poor by means of a cheap food policy. As we turn the corner of the curve into the developed world the emphasis changes in that the farmer pays full prices for his inputs but receives subsidized prices for his produce: it is all part of the process that defines the shape of the development hyperbola.

MARY TIFFEN (*Overseas Development Institute, London*). I congratulate Mr Hoffman on his paper, but as possibly the only economic historian present, beg to differ with his conclusions. It is true that large farms and developed agriculture are now associated. However, that does not mean one should aim immediately for the large estate. If the first step is to raise productivity and incomes on small farms, there is an increase in the demand for goods and services that can be provided locally. Consequently, labour begins to move off the farm into new jobs, causing a labour shortage, and an increase in mechanization that may then lead to larger farms. Other speakers have already noted that Asian farmers are raising their productivity, and in an evaluation of the Muda scheme in Malaysia, the World Bank notes that for every U.S. $1.0 of income generated on the scheme, a further U.S. $0.33 is generated off the scheme through the demand for local goods and services. In the southern United States and Latin America the move at an early stage to the large estate has generated a demand by a minority elite for luxury goods that can only be met by imports; there is no mass demand for local goods and services to generate off-farm jobs for displaced farm workers, and very unbalanced economies result.

G. R. HOFFMAN. Dr Tiffen has unique experience in the area of irrigated agricultural development and her comment is very relevant. However, it illustrates the major difficulty in any attempt to arrive at general principles when dealing with such a diverse and complex subject: there are invariably many examples which do not appear to conform. We did cover this in saying that concentration of effort ‘on the small farm is dealing with an interim state, applicable to some but not all of the developing countries, depending on their particular situation’.

We venture to suggest that such exceptions do not detract from the main thesis, which asks whether or not the progression outlined is inevitable and if so can we, as irrigation planners, move it along so that the benefits of higher production are reached sooner rather than later? We are not alone in suggesting that continued subsistence farming may mean continued poverty.

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